Poster #179

Low Flow Conditions Maximize the Impacts of High-frequency River Dynamics on Hyporheic Biogeochemical and Thermal Exchange

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This element of the PNNL SBR SFA aims to understand how the high-frequency flow variations control the temperature dynamics and biogeochemical fluxes within the hyporheic zone. Hydroelectric dams tend to increase the frequency of river stage fluctuation due to the relatively short temporal cycles of power production, while they also moderate extreme seasonal fluctuations with their ability to store and release water. However, little is known regarding the secondary impact of dam-induced flow variations on downstream hyporheic zone activity. In this research, hyporheic zone biogeochemistry and temperature were studied under variable flow regimes ranging from natural river flow (i.e. no dams) to high-frequency reservoir release common to power production. Natural river flow was synthetically generated by removing high-frequency fluctuations (e.g. subdaily). Hydrogeologic properties for this study were based on the Hanford 300 Area conceptual model with a high permeability Hanford Unit, underlain by a low permeability Ringold Unit and covered by a fine-grained, low permeability sediment at the riverbed. A vertical two-dimensional cross section was developed with a high resolution (10cm x 5cm) grid near the river. Hyporheic zone hydrologic and thermal flows were modeled through PFLOTRAN's thermo-hydrologic flow mode. Carbon consumption (i.e. aerobic respiration, denitrification, and biomass production) was simulated through a cybernetic reaction network with temperature-dependent rate constants developed within the PFLOTRAN reaction sandbox.

The multi-year (2010-2015) simulated exchange of energy and carbon mass within the hyporheic zone revealed that high-frequency stage fluctuations had their strongest thermal and biogeochemical impacts when the mean river stage was low. Seasonal decreases in river stage therefore coincided with the greatest impacts; the largest impacts were normally in the early winter when high frequency fluctuations cooled the hyporheic zone. An abnormally low snowpack in 2015, however, caused low river stage during summer months. The resulting high-frequency stage fluctuations at low river stage caused the hyporheic zone to warm. The spatial pattern of biogeochemical hot spots was found to highly depend on the heterogeneity in subsurface hydraulic properties instead of flow variations. This study provides a scientific basis for assessing the potential ecological consequences of high-frequency flow variations in a regulated river. The understanding developed from this study has motivated new research to connect hydrological exchange flows and their associated thermal and biogeochemical processes to mean river stage, frequency of stage fluctuations, and hydrogeology.